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BRIEF SURVEY OF GERMAN INFRARED DEVELOPMENT

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I am sure all of us, at one time or another, have marveled at the many spectacular devices that were used during the war, both by us and our enemies. Careful thought will bring out the fact that only about four or five really new ideas or developments came to light. First on the list would be the realization of the physicist's dream, atomic energy. Second place can easily go to radar, the utilization of radio waves to locate planes and do hundreds of other things. We cannot ignore the practical application of rocket propulsion that made the V-2 a radically new weapon. The use of penicillin, the various sulfo drugs and other almost miracle medical aids should occupy one of the places on this list.

To make the list complete we must add the military application of infrared radiation. I do not mean to imply that this was anywhere near as important as the others. It was however one of the really new ideas.

The discussion this afternoon will deal with the methods and devices as utilized by the Germans. I shall attempt to give you a concise over-all picture of the German effort. Drs. Weihe and Fischer in their papers will present detailed and specific data on specialized phases of the art.

A word about my sources of information. The material I shall present in this paper is of necessity second hand. By that I mean that I was not a member of any of the various investigating teams that gathered information and equipment in Germany. It was gleaned from the various classified intelligence reports and was secured by a long but interesting job of identifying German IR equipment, putting it together and attempting to make it work. It was gathered through conversations with members of various investigating teams and German scientists, and lastly all of the information was tied together and verified with reference to captured German documents.

As many of you in the field know, the real dawn of infrared came in 1935. It was at this time that several investigators in this country and some men in Germany, and perhaps other countries, turned toward the application of IR radiation to the solution of certain military problems. Suggestion along this line had been made earlier, as far back as 1919. In fact one or two attempts along this line were tried during World War I.

Just what were these military problems? Perhaps the best answer to this question is simply an enumeration of the uses to which IR has been put. For example:

a. The use of image-forming detectors for night vision with IR illumination,

b. Detection of heated objects with image-forming or nonimage-forming detectors.

c. Signaling, i.e., transmission of voice intelligence, blinker-signaling identification, aids to navigation, and infrared radar. Here radar is used loosely to mean the detection and tracking of planes and ships.

d. Miscellaneous applications, such as proximity fuses, automatic gunfiring, erecting IR barriers, etc., concludes the list.

Now what was the state of the art in Germany? Generally speaking, the Germans were ahead of us in certain respects. On the whole, the infrared devices they had, performed better than ours. The reason was, and I want to make this point clear, that very few of these devices were manufactured in large quantities. The Germans had a great variety of devices, but of some models only 5 to 10 and even less were actually built. The fact that they were captured at the front does not mean that they were widely used; it just means that the real proving ground, the battle front, was just around the corner for the Germans. For example, The German Bildwandler BIWA tube, equivalent to our mass-produced 1P25, performs better, but cannot be mass produced. It is a beautiful example of the glass blowers art with its various glass-to-metal joints, but a headache to a tube manufacturer. Our infrared viewing devices were light and portable; the German devices were always much heavier. It is important, when comparisons are made, that we carefully consider all the facts.

This immediately gives us a clue to the answers of a couple of questions that usually crop up after a person sees the technical excellence of German IR equipment.

Question one is: Why did they fail to make extensive tactical use of IR? The answer is simply that the device as a rule could not be manufactured in large quantities.

The second question is: Why is the German IR nomenclature (equipment names) so muddled? In digging through the literature, one soon becomes confused with the use of so many names and models of devices, such as ZIELGERÄTE, FAHRGERÄTE, ORTUNGSGERÄTE, BEOBACHTUNGGERÄTE, TAGESGERÄTE, SEEHUND, ADLER, IGEL, VAMPIR, FALTER, PUMA, UHU and many, many others. The German had many models, but relatively few of each model. I shall not attempt to confuse you with the various devices, but rather discuss the general type of the equipment in each case.

Let us consider first of all the various types of German detectors for IR radiation. They are basically of two types, the nonimage forming and the image forming. Here in slide No. 1 we have a chart showing the useful nonimaging detectors. Of special interest is the data in column 3; the long wavelength limit of operation. The limit of 16 mu given for thermocouple and bolometer is obviously the limitation due to the blackening layer of the device.

I shall not spend any time on the first one on the list since most of you are familiar with it. I should like to discuss in some detail the next three. All of these, the thallofide, lead sulfide, lead selenide, and lead telluride, all depend upon the inner photoelectric effect. I shall not go into detail concerning the theory of the photoconductive effect of semiconductors for the story is still not very clear. There are many rough spots in the theory that must be cleared up. The effect itself has been known for a long time. J. C. Bose received a patent in 1901 for the discovery of the fact that natural galena crystals changed their resistance when illuminated. Some of you may be familiar with the old Case cell as described in the "Physical Review" in 1917. The Case cell was sensitive in the infrared, but was very delicate. It had to be handled with kid gloves, so to speak. The Germans improved on the Case cell with their thallofide cell but the PbS cell soon replaced it. It appears that the Thallofide cell was brought to a higher state of perfection by Cashman in this country than by scientists working in Germany.

The lead sulphide cell was one of the projects on which the Germans really concentrated. The following incident will serve to illustrate this fact. In 1942 the Germans held a symposium on infrared techniques. Experts in the field presented a series of 15 papers during the two-day session. Out of these 15 papers, 8 dealt with the semiconductor cell and closely related topics.

A great deal of the serious work was done at AEG in Kiel. The work started with natural galena crystals. Several cells, made of a geometric arrangement of crystals, were built. These cells were not bad performers, but you can imagine that they were naturally quite delicate. The next step obviously was the utilization of synthetic PbS layers. It was soon found that the sensitivity could be increased by a factor of 20 to 30 if the temperature of the cell was brought down to that of liquid air. Up to this stage of the game, these cells exhibited quite a pronounced photovoltaic effect. Soon cells could be produced with no photovoltaic effect at all, but performed excellently as photoresistive elements. At first, liquid air was used for cooling, but this was not a practical method. Solid carbon dioxide (dry ice) would be much more desirable coolant. Unfortunately, the cells seemed to have a steeper improvement gradient near the liquid air temperature. Soon, however, cells were produced whose optimum performance actually centered around -65°C the dry-ice temperature. This was a great step forward, for it allowed a sound mechanical design of the cell. Here are some views of a standard cell. (Figs. X1, X2) A plug of dry ice, produced by a simple expander mold attached to a standard CO_2 cylinder, was held in contact with the wall on which the PbS was deposited. A charge of dry ice would last from 6 to 8 hours. The cells were made in several sizes and were fitted with Duran glass or quartz windows. The applied voltage was generally around 50 to 100 volts.

When the war ended, the lead-selenide cell was being worked on as energetically as the PbS cell had been before. The problems were similar. The selenide cell has the distinct advantage of having a greater long wave-length limit. It was designed specifically to utilize the 4-mu atmospheric window. Dr. Fischer will have more to say about the characteristics of the various cells in the second paper this afternoon.

The next slide shows a compilation of data of image-forming detectors. The first is the cesium-oxide cathode-image-convertor tube. This is basically the electron telescope of Zworykin and Morton. Note that it is considered the standard of comparison. I shall have more to say about this tube in detail later on. The next two on the list have nothing to offer as far as improved performance, except that for certain applications, their other advantages outweigh their lack of performance. The fourth one is rather novel. Unfortunately none of the equipment is available for display. The evaporograph or EVAGERÄT of Czerny is quite simple, but nevertheless very spectacular. It is a true thermal detector. A thin film of volatile oil is deposited on a target membrane. An optical system, effective in the medium IR region, forms an image on the membrane. Visible light is filtered out and only the heat radiation is used for image formation. The differential heating of the membrane by the image causes evaporation of the oil layer at different rates at different spots, thus changing the thickness of the film. Illumination with visible light produces a visible image due to the interference phenomena. Attempts to bring this equipment from the laboratory state to the practical state were not too successful. The factors involved in the operation must be controlled very rigidly and anyone who has worked with service equipment knows what headaches would crop up. Incidently the time constant is very long at low source levels. Here however is definite proof that a picture can be produced by thermal means. Perhaps this evaporograph of Czerny is the crack in the door to that tantalizing land of thermal imaging. It may provide you with ideas.

As far as IR photography goes, the use was naturally limited. We should consider it here rather briefly, simply to make the survey comprehensive. The cameras used, naturally, were fitted with long focal-length lenses, since the greatest application in this field was the photography of distant objects. Lenses with a 3 m focal length and f:25 aperture were used. Special cameras with an interchangeable negative lens sytem gave focal lengths up to 40 meters. Special film materials were available from Agfa that had sensitivity peaks at 0.75, 0.85, 0.95, and 1.05 mu.

IR photography was used preferentially for reconnaissance purposes, such as determining changes in building construction, the detection of camouflage, the detection and photographic observation of convoys in the channel, etc. One of the 3 m focal-length cameras was used to photograph the radar installations on the Dover coast. A subsequent exposure with a special 28 m. focal-length camera gave enough detail to enable the German technicians to determine the wavelength from the antenna dimensions.

The positions of cross-channel guns and searchlights were located by the simple expedient of exposing the plate at night, and then without disturbing anything to produce a daylight double exposure. Stereographs on an 800 m base line were also taken.

The phosphorescent image converter was evidently not used extensively. The principle of operation is that a special phosphor is put into a metastable state by radiations of short wavelength. Actual flourescence is produced when the meta-stable phosphor is illuminated with IR light. The advantage of this method is its extreme simplicity. Small viewers can be built at a very reasonable cost. The KATERGERÄT was such a device. It was a light instrument, weighing less than 500 grams, that could be produced rather cheaply in comparison with electronic instruments. Roughly speaking, the sensitivity was approximately 500 to 1000 times less than the normal electronic Bildwandler. It did however serve a very good purpose. A patrol leader could determine whether he was being illuminated with IR because the range of a KATERGERAT against a spotlight was greater than the electronic viewer was with the light.

An even simpler device was an infrared phosphor button that could be worn and used as a warning device when the person became an IR target. It also had its use in marking land-mine fields and other areas. An infrared flashlight beam would make those glow buttons light up.

It is worthy of note that the work on phosphorus was done for the most part at the Philip Lenard Institute at Heidelberg by Professor A. Becker and associates. They evidently did succeed in preparing a phosphor whose longer wavelength limit was in the vicinity of 2 mu. The big difficulty seemed to be in the lack of stability.

A glance at the last slide shows that I have been working back toward the first viewer shown in the chart, the cesium Bildwandler or image convertor. It is by far the most important one on the list. It is perfectly fair to say that more military applications made use of this device than any of the others.

For the benefit of some of you who may not be familiar with the image-convertor principle, may I take a few seconds to review briefly the operation of the tube. An image of the object, either illuminated with IR or a self-emitting IR source, is formed by an external optical system on photocathode of silver-cesium oxide. The liberated electrons pass through an electrostatic field where they are accelerated and focused on a flourescent screen where a visible image is formed. The image is generally viewed with the aid of a magnifier. The primary image is filtered to allow only the long wavelength component (above 0.7 mu) to activate the cathode. The deep red filter used prevents the cathode from being damaged by excessive illumination in daylight, and serves the purpose at night of preventing the visible component from reemerging through the objective, and thus betraying the position of the observer. The tube, as you can see, is very simple in operation; not simple in construction.

The whole system is then simply a terrestial telescope in which erection of the image takes place in the electrostatic lens. The transformation of IR to a visible image is also carried out in this portion of the system.

Let us now look at some of the factors that need be considered to develop an efficient IR image convertor. First of all we must have a cathode that will emit as many electrons as possible when illuminated, and as few thermal electrons as possible. The silver-cesium oxide cathode is the only one that can be considered. As many of you know the production of such a transparent cathode is quite complex. The total sensitivity and spectral range can be shifted quite readily by the thickness of the silver layer, the amount of free cesium, and by the method used in the production of the cathode. Unfortunately, the limit of sensitivity on the long-wave end is around 1.2 mu. Our constant wish and hope (not too much hope either) for a cathode going to longer wavelenghts and of greater sensitivity, seems to have been shared by the Germans. They recognized the extreme difficoutly of this job. A reduction in work function is needed, without increasing the thermal and field emissions.

There are two other ways in which the image tube can be improved, in order to get an apparent increase in sensitivity by an actual increase in brightness. The electrons could be given greater energy by increasing the accelerating voltage. The Germans evidently went as far in this direction as practical. Operating voltages up to 20,000 volts were not at all uncommon. You can see the added difficulties that high-operating voltages of this magnitude would engender.

The third method of producing appreciable gain in operating efficiency is improvement in the flourescent screen. A phosphor having great conversion efficiency is very desirable. It is, of course, also necessary that the visual output be in the spectral region of maximum eye sensitivity. A truly fine grain structure will definitely increase the possibility of good resolution.

So much then, in a superficial way, concerning the image tube. The Germans admittedly carried the improvement of cathode-focusing system and screen to a very high state of perfection. Improvement in present tubes can only come slowly and painfully. The best bet seems to be tubes operating on a somewhat different principle.

Since I have attempted to give you only a very generalized picture of the Bildwandler of BIWA system, suppose now we consider the more detailed operation of the image tube. In this slide (4-A) we have a detailed schematic cross section of a two-cathode image convertor tube. Since the potential gradient in the vicinity of the photocathode is rather small, considerable scattering of electrons would normally take place. These electrons must be collected and brought to a point on the screen. The collection and focusing is facilitated by this curved cathode. Note that the field is curved considerably so that radial acceleration takes place. This simple curved cathode, hollow cylinder anode arrangement can readily produce an acceptable picture. It is interesting to note that due to the cylindrical anode the cathode potential field extends somewhat beyond and into the anode opening. This field produces a radial spreading effect on the beam that nearly offsets the effect of the concentrating field, thus producing almost parallel electron rays and shifting the focal plane beyond the normal position. The very fact that the rays are nearly parallel during the last one-third of this journey gives us a great depth of focus. The resolution can be made approximately 50 lines/mm and the two electrodes simplify the design and operation.

To utilize higher voltages, the three-electrode tube was a logical development. The addition of the second anode, allows a much higher potential with the resultant increase in brightness. By making the potential on the second anode or the cathode variable, the field pattern can be so adjusted that better focusing will result. Actually it is possible, according to a German report, to secure a resolution of 1000 lines/mm, although the grain of the screen will never allow such a figure to be reached in an actual tube.

In order to reduce the high field emission from the cathode, a conical cathode shield is introduced. This reduces the potential gradient near the cathode, and thus reduces this disturbing emission to an appreciable extent. By cooling, the thermal emission can be reduced to a negligible value. Thus the background brightness can be reduced so that greater sensitivity can be achieved. It is claimed that the sensitivity can be enhanced to such an extent that radiation from a black body at 210°C can be detected.

Obviously the number of anodes is not limited to 3, nor is the voltage limited to 20 or 25. Experimental tubes with 5 anodes and 50,000-volt potentials have been built. Reinversion of the image by electronic means has been accomplished, although it is of no particular value. A variable magnification tube, as a result of varying the focal length, has also been tried.

Here are three tubes as actually produced and used in practice. (Slide) I'm showing these as typical examples. The AEG tube with its characteristic curved cathode and flat side is the medium size of their line. The other two are Reichspost tubes, a small one, and a medium-sized one. They have flat cathodes and curved sides. Each firm produced three sizes. I believe that most of the tubes are on display.

Many attempts to get greater sensitivity and longer wavelenghts operation have been made. A tube using secondary emission had been built by AEG. An increase of brightness by a factor of 20 could be achieved. The big difficulty was the difference in velocity at different points in the electron stream. Another attempt, not too successful but promising, was this double-image convertor. (Slide 7a.). Here was a true electronic light amplifier, but the difficulties were the lack of definition. In order to get maximum definition the separation between the screen of the first tube and the cathode of the second tube must be extremely small, and that is very difficult to achieve.

Electron mirror tubes using PbS or other semiconductors have been tried, and a great deal of work was being done at the close of hostilities. They are extremely interesting and promising. You will recall the first slide showing the various types of nonimage-forming detectors. The limit of the external photoelectric effect is approximately 1.3 mu, while the photoconductive type of cell goes out to 5.5 mu and perhaps better. If now a reasonably sensitive photoconductive-image convertor could be built, it would be possible to see objects at reasonable temperatures by their self-radiation. Thus we could actually see an "image" of a man provided the background would be at a lower temperature.

The operating principle is relatively simple. An IR image is projected by optical means on an electron mirror consisting of a thin film of a semiconductor such as PbS. The internal photoelectric effect changes the conductance of the material in approximately direct proportion to the amount of light falling on the layer. A thermionic cathode emits a uniform stream of electrons that is allowed to fall on this photosemiconductor. This homogeneous electron stream is of course accelerated, and then slowed down so that the "penetration energy" of the electrons can be controlled accurately. The ratio of penetration into the layer over the reflection is then a function of the characteristics of the material and incident illumination. The reflected stream is then diverged by a magnetic field, accelerated and focused by an electrostatic field, and then forms a visible image on the flourescent screen. The actual operation of reflection from this electron mirror depends upon the potential which is built up by the incident homogenoous electron stream on the upper surface of the semiconductor cathode and on the transparent metallic cathode support. As a result of the high resistance of the PbS layer an actual "potential gradient picture" is built up. The next slide shows what kind of visual images can be achieved.

I have referred constantly to PbS as an electron mirror. Actually the use of PbS as such had not progressed beyond the preliminary stages. I referred to it merely because I had discussed it to some length before as the best all-around semiconductor. In the experiments that the Germans performed with electron-mirror tubes, they actually used a Bismuth selenide-selenium surface. Although the response went out to about 2 mu, the sensitivity was appreciably less than the ordinary image tube. The reason that the lead sulfides, tellurides and selenides cannot be used at the moment is that sufficiently high resistances have not been achieved. The experience of German workers showed that in order to produce a usable picture with a light value of approximately one lux, a specific resistance of 10^9 ohms/cm is required. PbS at room temperature has a value of only 10^4 ohms/cm. By cooling to the temperature of liquid air, the value goes up to only $6x10^7$ ohms/cm. No doubt this image tube can be improved and eventually brought to the point where practical operation can be expected, but progress will be slow unless some other more favorable material can be found.

Since I have covered the theory of the image tube more or less in detail, let us now turn our attention to some of the actual applications. The biggest use of the IR image convert rs or Bildwandlers for night vision with reflected IR light was the army. They had equipment ranging from the small VAMPIR for mounting on a rifle, to the large GROSSBILDWANDLER with 60-to-90-cm mirror objectives. The common uses for IR viewing devices were; night driving, armored vehicle fire control, and small arms fire control.

For night driving the various FG (Fahrgeräte) were used. The need here was for a relatively large diameter viewing lens so that both eyes could be used for viewing. Since the instrument was fixed in position, a fairly wide angle of view was desired, thus the lenses were generally of shorter focal length for this application. For light sources, IR filters were slipped over the normal headlights, or conversely, if IR spotlights were to be used for driving, a simple beam-spreader lens was placed in position. Various reports stated, and there is no reason to doubt the statement, that it was possible to drive as well with this equipment as with normal lights. I do imagine that it did take a little time for the drivers to convince themselves of the fact.

For gun-laying equipment the term "ZIELGERÄT" was used. In general this equipment consisted of a BIWA system of large aperture and fairly narrow angle of view, and a narrow-beam searchlight, both bore-sighted with the gun. I have some pictures here of a typical installation. This happens to be the ZG 1221 (Pix 10a 11a 12a). The searchlight is a 100w12V unit using a narrow beam to get a range of 300 to 400 m. The visible component is eliminated by a double IR filter.

The viewer had a total magnification of 4 times and the angle of view was 10°, of which the central 5° exhibited maximum resolution. The operating voltage provided by the power supply was 18kv. The power supply required the standard 220v AC which was delivered by the invertor from the 12v storage battery. Another version of the same equipment mounted on a small antitank gun is shown in little more detail in the next four slides. (Pix 13a 14a 15a 16a). I might mention that the reflectors used were of very good quality and the bulb was always a spherical one, with the upper half accurately silvered to a very bright mirror finish. The bulbs were evidently manufactured to very close tolerances, for the reflected image of the filament was superimposed exactly on the filament itself.

To provide a sighting reticule, a small flashlight lamp was used to project a tiny photographic slide-sighting circle onto the cathode. There is an interesting angle in connection with this sighting-circle projection. It would appear simpler to just scratch crosshairs on the fluorescent screen, in fact this is actually done on some of the lighter equipment. However since the electron stream is affected by a magnetic field as well as an electric field, the earth's magnetic field, concentrated by the mass of iron of the gun and mount does deflect, and may distort the image. If the image of the sighting reticule is distroted and shifted by the same amount, no harm is done.

A similar piece of equipment is the IGEL III as shown in the next picture (17a). It was designed for naval use with a standard 90 cm searchlight covered with an IR filter. Note the size of the 30 cm f:1.5 objective. The angle of view was 6°. The range with the above-mentioned searchlight was 5,000 m. Ranges like this can be achieved only with large searchlights located at some distance from the observing instrument, otherwise the scattered light from even a well-collimated beam will block out the view. Larger searchlights were used, and with even larger objectives on the viewers, ranges up to 10 km could be achieved.

Please understand that such ranges could be achieved only with large navy apparatus, and then only under ideal conditions. The best range on land was perhaps achieved by the UHU equipment. This consisted of a 60 cm carbon arc searchlight with a 40-cm IR filter, together with 6 kw power supply, mounted on a half-track. The use of this vehicle was mainly for leading tanks and for reconnaissance. A formation of 5 Tiger tanks would have one UHU. This enabled the tanks to approach close enough to the target so that their own aiming equipment with a 400-meter range could be brought into play. With the half-track providing the illumination, the tanks could use their viewers to fire at about 700-m range. The maximum range of the UHU equipment with a large viewer was about 1500 m. If, for some reason, it was not desirable to attack using the IR equipment, the UHU half-track, generally equipped with an 8-cm gun could fire flares to illuminate the target normally.

Reports have come in telling of the effectiveness of this equipment in tank warfare. A German tank outfit, dug in on the Russian front on the defensive, succeeded in knocking out 67 Russian tanks in one night. Fortunately, for us, only about 60 pieces of equipment out of the 600 ordered were actually delivered.

On the other side of the size scale was the "VAMPIR", a rifle-mounted searchlight and viewer, the equivalent of our recently publicised "sniperscope" developed and used by our ground forces. The equipment, although heavier than ours, did have one novel feature. It it to be remembered that the image converter tubes draw very small currents. The power supply of the VAMPIR, built into a gas-mask cannister, made use of this fact by utilizing the charge stored in the filter condenser to operate the tube. The operators would simply press a button starting the vibrator power supply which in a few seconds would bring the charge on an 0.1 mf 15,000-v condensor up to from about 8,000 to 10,000 volts. The charge would then be sufficient to operate the viewer from 5 to 10 minutes. Another small viewer designed specifically to spot IR sources was a fairly compact binocular. One side of the instrument was a conventional prism night glass, while the other tubulature of the binocular contained a small BIWA system. Matched crosshairs enabled the observer to spot the position of an IR source in relation to the surroundings.

Then there was another use of the Bildwandler IR telescope that was routine with the navy. It was the transmitting of intelligence via IR blinker signals. With large searchlights and relatively compact viewers, the range was just about as great as with visual light. A typical small blinker installation is shown in the next slide (18a). Here is the picture of a small IR signal lamp and another picture of a large searchlight for the same purpose. (19a 20a).

The fact that IR does penetrate haze, and certain kinds of small particle dusts and smoke, makes the TAGESGERÄT shown in the next picture (21a) of some value in daylight. It does increase the visual range by a factor depending on the condition of the atmosphere. That factor had a value of only one during conditions of fog and large particle smoke. It is to be remembered that the near infrared <u>does not</u> penetrate fog any better than visible light.

A different use of the BILDWANDLER was the passive detection of aircraft. Aircraft engines emit an appreciable amount of energy in the spectral region where the image convertor tube operates, especially our engines, since our pilots were always "pouring on the coal" and thus ran their engines hotter than the Germans. The ADLERGERÄTE were the series of instruments that operated on this principle. In these pictures (23a 24a 25a) of the ADLER II a large viewer is mounted on a standard base for one-man operation. The unit was used with some success for searchlight direction. The azimuth and elevation information was transmitted via selsyn motors to the searchlight directors. Another version is the two-man operated unit shown in the next pictures (26a 27a 28a). One operator tracks in azimuth while the other tracks elevation. The binoculars are a precaution against the possibility of confusing the response from a star for that from a plane. In fact this is one of the weaknesses of this system. Toward the end of the war emphasis was placed on heat detectors using PbS cells rather than BIWA devices. It might be pointed out that careful shielding of the exhaust would cut down the range of this system tremendously, for a lower exhaust temperature would place the energy out of the spectral range of the image-convertor tube. This fact alone makes the lead sulfide type of detection almost imperative.

Perhaps some of you have wondered about the very large objectives that are used on the big installations. They are large apertures, long focal length, high quality objectives made by Zeiss, Leitz and Busch. Apertures of f:0.85 with 15 cm focal length, and f:1.5 at 40 cm focal length were used along with "slower" lenses, some even as slow as f:2. Most of them were antireflection coated for the 1.1 mu region. I'm showing the next picture, a cross section of an ADLER BIWA, simply to show that the objectives were not one-or two-element lenses. Needless to say a f:1.5, 40 cm lens was not one to carry around on your candid camera.

Now let us consider in brief-survey fashion some of the other interesting infrared components.

I mentioned just a moment ago that as far as aircraft detection goes, the PbS cell was replacing the image-invertor instrument. Dr. Weihe will go into detail on the operation of units like that in his discussion of Kiel IV. The BII shown here is a general example of this type of equipment. A mirror system scans a field of view on a PbS cell. The pattern is repeated by the scanning of the electron beam of a cathode ray tube. The signal produces Z axis modulation. Other indication methods have also been used. In this particular system, scanning is accomplished by the spiral motion of a plane placed 1/2 the focal length from the parabolic collecting mirror and the cell.

This is about as close as the Germans came to an infrared radar device for aircraft use. It was possible to detect planes, to track them accurately, and to pass on this information to the searchlight control center. It did not give an indication of range. The ordinary radar technique of pulsing energy and timing the interval during energy transit was tried but found wanting. As Dr. Fischer will discuss later, against larger targets, some measure of success was achieved.

To supply the missing range information attempts to utilize optical rangefinder techniques with the various heat detectors were made, but too many difficulties cropped up. The idea, however, of detecting and ranging passively against a target is a promising one, and with the improvement of components and techniques will no doubt become well established.

The WÄRMEPEILGERÄTE or WPG were similar to the other devices mentioned in that they were heat detectors used to detect a body at higher temperature than its surroundings. The general scheme was simply to place a bolometer or thermocouple at the focus of a parabolic mirror and to pan the equipment slowly. There was no scanning in the sense that we usually think of it because of the long time constant of the detecting element. We will hear more about the theory and operation of this type of equipment in a later paper.

There were many attempts to develop a heat-seeking missile. LINSE of Zeiss and WASSERFALL were two such devices. They were never actually used but were in the last stages of development when the time ran out. A PbS cell was generally used and the radiation from the heat source was interrupted by a chopper disk to produce a readily amplifiable signal. WASSERFALL had two overlapping chopping disks with their centers displaced so that at the beam aperture their tangents are at 90°. Thus with two sets of periphial modulation tracks, four distinct modulation frequencies are produced in the four quadrants. These are the conventional Cartesian quandrants displaced by a rotation of 45°. Selective amplifiers feed a proportional control circuit, and the missile will follow a "dog curve" course. LINSE is similar, but since it was to be applied to a self-steered boat it needed only right and left control. A single disk with two periphial tone tracks divided the field into two areas with distinct frequencies. Either mirror or refractive optics were used for these applications.

The material for the refractive elements might be of considerable interest. The Germans had done a great deal of work on synthetic crystals exhibiting interesting transmissions characteristics. Silver chloride and silver bromide crystals were known under the code names of KRS 11 to 13, KRS 13 being a mixture of the two silver halides. The extremely interesting ones were the KRS crystals numbered below ten. They were the thallium halides and were extermely toxic. KRS 5 is especially interesting because of its excellent transmission in the infrared region. A curve of the transmission vs wavelength is shown in the next slide. This graph came from a German report. Several laboratories in this country are checking the characteristics of the material, but we have no reason to doubt that this is not an accurate representation. The material is pink and has a slightly greater hardness than NaCl. Plates up to 10 cm in diameter were turned out. The material was also used to make compound lenses for various heat-seeking devices. The optical components were coated for elimination of reflection losses. The index of refraction of KRS 5 is around 2.4. KRS 6, a clear material, had an index of 2.2 and did not transmit out quite as far into the infrared. The KRS materials were developed and turned out by Smakula at Zeiss in Jena.

So far I have said nothing of filters. The Germans followed about the same pattern as we did in this country. Organic deposits on tempered glass were the standard filters. They were fairly efficient and it was felt that for all ordinary IR applications they were perfectly satisfactory.

Carl Zeiss and Schott Glass Works had developed a line of interference filters that were capable of giving extremely narrow band-pass characteristics. With these filters it was possible to isolate certain spectral bands, to produce practical filters having very steep transmission curves, and even to simulate the transmission characteristics of the atmosphere.

One more application that might be of interest, the various types of LICHTSPRECHER or light beam telephones. There was nothing really new here. Three schemes of mechanical modulation were used besides an electrical method. The mechanical methods used were: (a) a rocking prism scheme that has been explained in detail in technical journals in this country, (b) a prism grid that was capable of 100% modulation, and (c) an opaque-grid method. The electrical modulated LICHTSPRECHER used a high-pressure mercury arc as a light source. All of the receivers used either a thallofide cell or (later) a PbS cell.

There are several other IR items of interest that I could discuss, but my time is limited. It was extremely difficult to decide what should be included and what might be omitted. I hope that I have succeeded in my attempt to give you a general picture of the equipment and the uses to which infrared radiation was put by the Germans. The other speakers on the program this afternoon will go more into the technical details of certain phases of the program, and if my talk has given you a general insight of the situation so that you can fit the individual pieces into a clear undistorted picture, then it has served its purpose.

Thank You.

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